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Cost-effectiveness analysis and joint public production of outputs for development: a preliminary framework

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ABSTRACT

The 2030 Sustainable Development Goals are highly interdependent. Lasting progress towards these goals requires collaboration among actors operating in diverse sectors and thematic domains. Yet, multi-sectoral collaboration is complicated by a variety of factors that tend to incentivise siloed action organised around individual interventions and budgets. This paper presents an analytical framework based on the concept of "economies of scope" for assessing and enhancing the efficiency of development projects for which there is a joint production process. We focus on the use of fair cost sharing methods such as the Shapley Value to dis-incentivise actors operating in inefficient siloes.

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I. Introduction

Cost-effectiveness analysis (CEA) is a valuable analytical tool to help policymakers and practitioners decide how to efficiently allocate scarce resources to achieve development outcomes. However, there is insufficient guidance on how analysts should account for situations in which multiple projects, whether led by a single or multiple organisations, share inputs in the implementation of their respective interventions. This is a common scenario and is likely to become increasingly so as international development actors have come to recognise the interdependence of their respective objectives while also adapting to tightening budgets. How should costs be allocated (for direct budgetary or fiduciary purposes) to goods and services that are produced through a common public production process? This paper outlines a preliminary analytical framework for tackling this thorny and under-emphasised but critical issue. Moving beyond the current suggestions, which some have cautioned to be arbitrary (American Inst. for Research 2021), we show that there are analytical techniques with standardised approaches for cost sharing that exploit the fact that common resources are used to generate savings or economies of scope. These methods should find usage in CEA studies.

Production processes produce output in the form of goods and services; public production processes produce programmatic outputs that practitioners and policymakers expect will facilitate socially favourable outcomes among recipients. CEAs help to assess the social production cost of programme outputs produced in the public sector to achieve these outcomes. Examples of outputs include vaccinated children, number of agricultural workers trained, enhanced production-level per household or village, or number of ponds constructed. Some authors would call exercises that report cost weighed against such outputs as cost-efficiency analysis.[1] Such programme outputs in turn

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contribute to development outcomes. Increasing the number of vaccinated children, for example, produces disease prevention in the community which in turn engenders improved health and well-being. When these development outcomes can be monetised, the analyses that weigh costs and benefits have been called cost–benefit analysis (CBA). For the purposes of this paper, we use the terms 'CEA' and 'output' in a generic sense to encompass all of the above constructions of the 'effect' side of the equation (programmatic outputs, development outcomes, and subjective valuation), since the proposed approach can be applied equally in each case.[2]

In case the goods and services from the production process can ultimately acquire a monetised value (where CBA is applicable), and when the budgeted amount for a project yields a threshold rate of return, then the project can be thought to be efficient. This has been the standard practice with some variations based on the once vibrant, well-researched field of project cost–benefit analysis (Dasgupta, Sen, and Marglin 1972; Little and Mirrlees 1969). In cases where the rate of return is at the margin of threshold, it may be necessary to assess project costs in detail, rather than assuming (as is often done) that the project budget is equivalent to the actual costs it will incur. When carrying out CEA for a project, it is likely that we need to know the cost of an output more carefully, as it will often be asked what an acceptable cost would be to produce it. That is, we ask: 'does the society value the output and outcomes of the public production process enough to undertake the cost reported?' as opposed to 'does the budget yield a rate of return higher than the threshold rate of return?' The fact that budgets and actual costs often diverge substantially makes this distinction important and underscores the need to focus on estimating the latter as accurately as possible.

As is true in the private sector, in many cases public sector provisioning of goods and services can be produced jointly with some sharing of inputs in the public production process. Joint production processes may occur within an organisation or across organisations. Examples are plenty: integrated vaccination programmes offering HIV testing, feeding programmes facilitated through schools, education projects that involve vocational training and access to financial services. Some goods in the public sector are produced jointly by two or more different actors while sharing inputs. It is also common that multiple outputs may be necessary or complementary to achieve a given development objective.[3]

Economic theory argues that in private production processes, in a relatively competitive market, the joint production process can only exist if it is efficient. Following Panzar and Willig (1981), this means it must exhibit economies of scope (EoS) such that costs when producing two or more different types of outputs jointly are cheaper than the combined costs when produced separately. However, public production processes are more likely to arise from deliberation of those in power or through a direct public mandate, rather than from market forces. Thus, some assessment of the production process should qualify whether it should be pursued, expanded, or replicated. We focus on technical efficiency, which can be understood as the least cost way of producing an output or being within a socially acceptable cost ceiling.[4] The definitions of technical efficiency are the same in both public and private sector (Baumol, Panzar, and Willig 1982; Panzar and Willig 1981).[5] In our framework, the standard definition for EoS will be expounded to determine whether joint production should be followed.[6]

Joint production involves multiple development actors, such as departments or organisations, producing multiple outputs. In some cases, development actors share an input to produce goods or interventions. For example, a particular production input, such as a new community centre, could be shared by both health and education projects to reduce costs. Actors here take advantage of EoS.

The literature recognises that joint usage of resources can generate economies of scope (Vassal et al. 2018). An intuitive approach that has been suggested is to measure the intensity of usage of common resources by each interventions and divide the costs proportionally (Drummond et al. 2007). Imagining the difficulty of ascertaining the intensity of usage, some recommend (American Inst. for Research 2021; Shepherd, Zeng, and Nguen 2015) that for any common use of inputs, its cost be divided equally among the number of users regardless of the relative intensity of usage by each. It is important to divide the cost of the input across the interventions for a number of reasons: (1) to know the true cost of producing a given output even when production occurs within a given organisation using a single budget envelope; (2) when we find joint production of multiple outputs produced by multiple departments, we may need to appropriately apportion the total costs as budgets to the departments. Exactly how to allocate these costs, however, remains up for debate; a prominent set of researchers saw 'evangelical attempts to eliminate' serious discussions on the topic from accounting (Billera, Heath, and Verrecchia 1981).

Our paper proposes methods for cost sharing for the joint use of inputs and production. The methods we propose are not new, though they have not been the staple methods for CEAs, particularly in the health sector, which has a rich CEA literature. Our approach takes advantage of the possibility that joint usage of inputs (which sometime can be joint usage of the entire production process) can yield savings compared to usage of separate inputs for each project or intervention. If it is possible to know what individualised input usage or a disaggregated production process would cost, we would know the exact savings generated by the joint processes. This in turn would enable a systematic, nuanced approach for allowing us to distribute the savings among the individual projects or interventions.

The purpose of this paper is to contribute to discussions around costing of public production of multiple outputs and what it implies for efficiency in comparison to alternative ways of producing. As joint production processes in the public sector have not been examined in detail, the framework is preliminary. The rest of the paper proceeds as follows: Section II discusses what we mean by joint production. In Section III, we detail the standard efficiency criterion for joint production, with a discussion as to its usefulness. Section IV presents methods for cost sharing in joint production and how to distribute its gains. Section V offers limitations of the approach. Section V concludes.

II. Joint production

To put the discussion in the context of the literature, some basic definitional notion of CEA is appropriate. This is done for a single output to focus on costs. Cost-effectiveness analysis juxtaposes costs and development outcomes (which, as noted above, we group within the umbrella term 'outputs'). Production and costs stand in mathematical primal–dual relationship to each other if efficiency in input usage is achieved given the prices of inputs and the production technology. Costs and the level of output report a near mirrored aspect of provisioning of a good (Silberberg 1990). CEA results are commonly summarised using the cost-effectiveness ratio (CER) or the incremental cost-effectiveness ratio (ICER). The ICER is derived by comparing the output and costs of status quo activities to those that ensue from activities (the new) replacing the status quo. ICER is defined as:

$$ICER = \frac{\textit{Cost of new activity} - \textit{Cost under status quo}}{\textit{Output under new activity} - \textit{Output under status quo}}.$$

The CER is equivalent to average cost and is most relevant when the development actor (say, the government) would be interested in producing a new type of output by adding a project that does not replace any current activity. When activities do not have any equivalent status quo, then ICER becomes the same as CER. For expositional reasons, we focus on average costs and CER instead of ICER.[7]

Taking two outputs, as example of public joint production process, for the society to produce them together, we must observe *subadditivity* in costs (the dual of an efficient production process). That is, the joint process should be cheaper than providing these two outputs separately.

In most production processes, multiple outputs are produced. Many factories will produce different but similar products where skills and machinery are used at the same time for multiple purposes. Research on EoS stems from observing market production. Panzar and Willig (1981) state that John Clark (1923) suggested that existing excess capacity in the production process can be eliminated through expanding production of other outputs. Public production processes are also capable of producing multiple outputs. For health projects, a cost-effectiveness guideline suggests that 'economies of scope' exist when multiple services are delivered jointly and relatively cheaply (Vassal et al. 2018). Although this study does not indicate how much research there has been to detect subadditivity, it concludes that empirical evidence of the extent of these gains for most global health interventions remains scarce. However, many recognise (Hauck et al. 2019) that joint production processes are common, as, for instance, all health care is delivered from a platform of human and physical infrastructure, which make up a health system. Drummond et al. (2007) suggest a process for costing overhead by finding the cost of a common input unit that all outputs will have used. For example, an intensive care unit is used for many types of medical interventions; a common element used by all of the interventions is bed-days in intensive care. In practice, it may not be feasible to divide up inputs (bed-days) or find the exact proportions or intensity of use to produce each output. The implicit idea is to divide the actual time spent on activities or intensity of usage; a specific application has been to examine how much time a worker spends for a particular task–time motion (Lopetegui et al. 2014).[8]

Subadditivity in the case of two or more goods will entail that goods are produced at cheaper costs when produced jointly than when each is produced separately. For instance, integrated development programmes (IDP), a type of multi-sectoral collaboration, simultaneously implement interventions in multiple sectors to generate complementarities and cost-saving synergies. Together with the 'big-push' theory of development, IDP would lift people permanently out of poverty (Masset, García-Hombrados, and Acharya 2020; Murphy, Shleifer, and Vishny 1989). A prominent application of 'big-push' yielding synergy and allowing a region to leap-frog out of poverty were the Millennium Village Projects (MVPs), a series of localised projects implemented in African countries to simultaneously affect local productivity and elements of the Millennium Development Goals (MDG). Interventions in agricultural productivity; health, nutrition and family planning; primary education; urban infrastructure and services; science and technology; gender equity; and regional integration were simultaneously implemented (Sachs et al. 2004). It was also thought that simultaneous implementation would prove to be cheaper in achieving the respective outcomes each sector would if implementation was piecemeal. An expected task for a CEA researcher could be to calculate from MVP, for instance, the average costs of full immunisation or retention of a school year.

Continuing with the example of the MDGs, the goals were to be pursued simultaneously in most countries. Typical of the approach to calculating the global cost of achieving the MDGs was the calculation of scaled-up unit costs (for some defined entity) for each goal and then added up to yield a final cost. Yet these goals are interrelated, and causal pathways connecting them are complex (Reddy and Heuty 2008).[9] Within a country, if a region sought to achieve the components of MDGs simultaneously, departments or organisations pursuing the goals could share inputs. Such concentration of interventions, even if carried out by disparate organisations, may yield results showing efficient production of singular interventions. This type of regional concentration has been described as an 'agglomeration effect' (Goldstein and Gronberg 1984).

A more common than IDP type of projects is the example of adolescent programmes containing components to prevent early pregnancy, decrease sexually transmitted illnesses, reduce early marriage, and increase economic opportunities and years of education (World Bank 2008). No single actor would be able to address all outcomes in isolation. This type of complex programme is likely implemented through shared and coordinated resource usage. Examples of a single actor producing multiple outputs are also not uncommon; for instance, a single budget envelope concerning nutrition may oversee the nutritional needs of expected and new mothers and all children 12–59 months. There may be a need for calculating cost drivers within the envelope, which would be the cost of the individual outputs.

The instances of interconnectedness we describe require an understanding of the joint production process for development outcomes. It is conceivable that we find both subadditivity in cost and its reverse, super additivity. The development literature has not addressed issues around EoS sufficiently.

III. Subadditivity: economies of scope

We define subadditivity more carefully and show how the definition can be used. When a production process yields multiple outputs, for it to be cost-effective, we must find synergy in the joint production process. Suppose that combined the joint production yields n outputs. At the least, the total cost of the joint production should cost less than the production of each type of output produced in a stand-alone approach. More strictly, there must not be any combined production processes containing less than the n outputs or stand-alone processes that yield lower costs. Panzar and Willig (1981) offer a concise definition of economies of scope or subadditivity. We annotate their exposition below.

Consider N outputs N, $N = \{1, 2, \ldots, n\}$, represent outputs by y, with $Y = (y_1, y_2, \ldots, y_n)$. Let $Y_s$denote the N dimension vector whose elements are set equal to the elements in y for $i \in S \subset N$ and 0 for $i \notin S$. The function $C(Y_S, w)$ is the multiproduct minimised cost value for input prices.

Definition: Let $T = (T_1, T_2, \ldots, T_l)$ denote a non-trivial partition of $S \subseteq N$, where $\cup_i T_i = S, T_i \cap T_j = \emptyset$ and $l > 1$.The partition could contain only one output or any set from S. There are economies of scope at Y_S with input prices w with respect to the partitions if

$$\sum\nolimits_{i=1}^{l} C(Y_{T_i}, w) > C(Y_s, w). \tag{1}$$

The inequality defines subadditivity formally; weak inequality is also possible to define economies of scope.

To see this in a more concrete way, we show a test for finding economies of scope (subadditivity) for the public production of three outputs in set S. Let three goods be observed at quantities (y_1, y_2, y_3). Supposing all combinations of the outputs can be partitioned and produced. The partition in the production processes would be a single combination of the following six possibilities, where items in the brackets are volume of outputs of each of the three types of goods:

$$P_1 = \{y_1\}, P_2 = \{y_2\}, P_3 = \{y_3\}, P_{12} = \{y_1, y_2\}, P_{13} = \{y_1, y_3\}, P_{23} = \{y_2, y_3\}.$$

And there is also the partition consisting of all elements of S, $Y_S = \mathrm{P} = \{y_1, y_2, y_2\}$. It is possible that we know the production costs of each of the possibilities above from past production. Previous costing studies may have determined the costs of these production processes. Furthermore, the cost of overall joint production is known. Consider the following production costs, where $C(Y_S)$ delineates cost function for all three levels produced together and define costs over different production combinations:

$$C(P_1) = 35, C(P_2) = 20, C(P_3) = 40,$$

$$C(P_{12}) = 50, C(P_{13}) = 65, C(P_{23}) = 55, C(Y_S) = 80.$$

To test whether joint production process should be undertaken, we conduct the subadditivity (synergy) test, through identifying two steps:

(S1) Testing for individual production over joint production:

$$C(P_1) + C(P_2) + C(P_3) = 35 + 20 + 40 = 95, \text{ note: } 95 > C(Y_S) = 80$$

(S2) Testing whether there are other combinations of joint production that are better than the joint production of all goods:

$$C(P_{12}) + C(P_3) = 50 + 40 = 90, C(P_{13}) + C(P_2) = 65 + 20 = 85,$$

and

$$C(P_{23}) + C(P_1) = 55 + 35 = 93$$

In testing with the combined partitioned production in step 2, we find all cost combinations are higher than 80. Thus, one can say that there are economies of scope in producing all three outputs.[10] Whether or not to produce these goods jointly is dependent on knowing what would happen in alternative production processes. This may be difficult. When one finds multi-output production processes in the market, it is implicit in Panzar and Willig's (1981) argument that the firm has understood that its production process is subadditive. The presence of multi-output production in the public sector may require explicit justification even if finding costs for different partitions is difficult.

For an MVP type project, implemented in Ghana (Masset, García-Hombrados, and Acharya 2020), the authors tested for economies of scope through the use of cost figures found in the literature. If the first step above is verified, then one tests what results would be obtained using the second step. The authors calculated the impacts of all activities that can be attributed to the MVP. The project costs were obtained through input purchase data. Thus, $C(Y_S)$ could easily be obtained through impact analyses and cost calculations of the entire project from the project data. The authors did not observe any stand-alone activities as reported in step 1 or the partition of a single product on the left-hand side of Equation 1 in the MVP project itself. Step 2 from above was not needed. There is no way of knowing what the alternative production processes would cost at the site itself. However, much of the literature on the cost of activities relevant to MVP was available from studies that priced stand-alone production processes. Most of the studies did not detail the context in which the studies took place. The authors noted that it was not clear in the literature if the contexts of the studies from which they used the costs were similar to those found in the Ghana setting. This observation underscores that many cost-effectiveness studies report costs from settings where efficiency could be affected by economies of scope or agglomeration, such as the Ghana MVP setting, which lacked basic health and educational infrastructure.

Detecting economies of scope is not easy where outputs are publicly produced. Jin et al. (2005) note, for instance, that similar settings may be present in multiple government agriculture research centres in China. These centres try to improve production processes that could be followed subsequently outside the research centres. The authors take advantage of the fact that some research institutes engaged in research on both wheat and maize and some in only one of the two crops. Using sound econometric methods and appropriate explanatory variables, they obtained estimates for variable costs for each of the crops where both types of crops were bred and where only one of the crops was tended to. They estimated the following using the definition for EoS as suggested by Baumol, Panzar, and Willig (1982), and similar to the one used above:

$$EoS = [C(Y_1 + Y_2) - C(Y_1 + 0) - C(0 + Y_2)]/C(Y_1 + Y_2). \quad (2)$$

If $EoS < 0$, then there is presence of economies of scope. Jin *et al.* show that the average cost per wheat variety is consistently lower in joint (wheat and maize) institutes than in wheat-only institutes, and, similarly, the average cost per maize variety is consistently lower in joint institutes compared with maize-only institutes.

Tests for determining economies of scope can be complicated. However, it is not irrational to believe that in most cases in the public sector there is considerable cost sharing and there may be positive externalities when simultaneous productions take place. We next discuss how shared inputs can be costed. We also suggest what might be an acceptable way to talk conceptually about the unit cost of outputs when multiple outputs are being produced.

IV. Accounting costs in multiple output production

Glandon et al. (2019) note widespread consensus that multi-sectoral collaboration (MSC) is essential to meet the developmental achievements set out in the UN Sustainable Development Goals (SDGs). Collaboration necessarily means that some type of coordinated activities must be undertaken to achieve some stated objectives (Rasanathan et al. 2017). The SDGs also involve production of multiple outputs. A set of outputs can be produced through efforts stemming from MSC, with resources shared between sectors. One of the underlying bases for MSC is EoS in the production process of outputs (for example, some components of SDGs) produced in the public sphere. MSCs have varied aims. Multiple sectors cooperate to produce multiple outputs to achieve more efficiently and cheaply a single developmental goal, for example, gender empowerment. MSC also engenders multiple output clusters, although some of which are the remits of a single department. Joint production processes or positive externalities due to simultaneous production yield results where outputs are achieved more cheaply or efficiently.[11]

To summarise, In the cases discussed above, the production processes of all outputs will have some shared uses of inputs. The shared inputs can be thought of quasi-public goods although non-rivalrous only up to a certain level of usage. It is assumed that this joint production produces lower average costs for all outputs (that is, subadditivity in costs or EoS).

CEAs usually account for costs through the ingredient approach, which takes into account the inputs used and costs them at opportunity cost. When inputs devoted to one use exclude other usages, the opportunity cost is simple to calculate. With joint production, it has been suggested as noted above that one needs to measure the intensity of usage, perhaps based on the proportion of total usage of a resource or more easily assign some estimate in terms of percentage usage (Drummond et al. 2015). We focus on cost sharing methods that rely on what alternatives might cost if cost sharing were not undertaken. The latter may not require estimating intensity in a precise way.

Cost sharing of one input: There are multiple methods for accounting for the cost of shared inputs. We present a few of the methods below.

The simplest way, and currently most recommended, to delineate cost in a situation of sharing input usage would be by measuring time or space usage. Many physical inputs can be lumpy or not easily divisible. Suppose a capital good is valued at $2,000 for yearly usage.[12] Two projects can share the use of the input at 30% and 60% of machine's capacity usage, with 10% of the time the capital good being unused. Call the higher percentage usage as the older usage. Then, a direct cost method would suggest the cost allocations to be \$667 $\left(= \frac{3}{9} \times 2000\right)$ and \$1333. Call this good capital good A, which has a value of $2,000 yearly. Observe there are savings for the older usage of $667 if the entire cost was borne by the older user before the new usage was made.

If the old usage was 70%, then there is no excess capacity from the older usage. The breakdown cost of new and the old usage would be $600 and $1600. Consider now that with the new user's more intense usage, the good requires greater maintenance increasing the cost to, say, to $2400. Then, the breakdown of costs becomes $720 and $1680 for the new and old usage, respectively. In calculating the costs of input usage, these scenarios are plausible.

Capital goods are lumpy, but they may also exhibit economies of scale in that as they are used more for even a single purpose, they drive down the cost of that single output. It is also possible that a bigger unit of a capital good is cheaper to produce and use with increased scale usage. For the same type of capital as in *A*, a unit capable of carrying out 40% use capacity of *A* may be priced at $1000 per year usage, while *A*, though more useful by 2.5 times, costs only twice as much. If *A* is already in place for older usage, the new user could have an option of buying the new product. Sharing inputs allows the society to not spend the extra $1000 on buying more inputs. There are savings of $600 (3000–2400) for the newer usage. As Shepherd, Zeng, and Nguen (2015) have noted, it is difficult to determine the share of usage and the intensity of usage. We may have no idea how much the newcomer would use. If we know that a new user has a lower-level need for the input, and there may be enough excess capacity in the current usage *A*, implementers are likely to think joint usage is possible. How then could we divide the cost? Perhaps, we can use some standard methods of cost sharing in accounting. The usage *A* currently is a quasi-public good (non-rivalrous up to a point); we may propose the following:

Proposal 1: Since 1,000 more would be spent without cost sharing, assuming that joint usage cost is 2400, the new project can be charged through proportional costing based on what would have been paid without cost sharing (2000 + 1000):

$$\left(\frac{1000}{3000}\right) \times 2400 = \$800 \text{ while the old project would becharged } 2400 - 800 = \$1600$$

Note that this type of costing apportions cost according to alternative expenditure rather than the intensity of usage. This may be thought of as a fair means to allocate costs. If the users were from different departments, they may be willing to incur these costs based only on what the alternative is. This method is known as the Moriarty Method (Lemaire 1984).

Proposal 2: Marginal costing for either of the two allocations depends on which one we see as the primary project. The primary project could be either of the two projects; this yields two possible cost allocations:

Allocation 1: Old Project $2,000 and New Project: $400, or
Allocation 2: Old Project: $1,400 and New Project $1,000.

It is possible that for some allocation methods such as the one above an organisation may not want to go along; there could be a preference for the status quo from either of the users.

Proposal 3: Average marginal costs:

Old Project $1,700 and New Project $700.

In the two-user case, the average marginal cost is equivalent to reimbursement from the total gains equally divided (Lemaire 1984; Young, Okada, and Hashimoto 1982).

Proposals 1 and 3 are acceptable, as both projects get to save costs to the users. In cost division literature, this can be thought of as meeting the participation constraints; that is, the projects incur lower costs by agreeing to share available resources.

In conducting CEA, lumpy inputs are rarely noted, though the AIR-recommended methods (American Inst. for Research 2021) are an exception. An input may not be fully used yet still costed fully in the production of an output. Cost sharing is only possible if resources are not fully used in a single use. With the cost sharing methods we have presented, some notion of intensity of usage is implicit when smaller units of the physical inputs are available and may be useful for the newer project with which the input will be shared. The calculation of intensity of usage relates to how much unused capacity a lumpy input has and how much additional capacity is needed for the joint usage. The penalty for miscalculation will depend on the lumpiness of the input. The methods presented to price cost-sharing calculate acceptable prices in a constructed market; thus, they are actual economic costs.

Cost-sharing with multiple outputs: Many outputs can be the product of an integrated production process whether between projects in a single organisation or between multiple organisations. We propose that we understand costing of outputs in joint production through the cost of items in alternative situations. There are other means through which to divide costs (see Lemaire 1984; Young, Okada, and Hashimoto 1982), but we will present only one of them. The method can incorporate the possibility that multiple outputs in many settings involve different organisations who would need compensation that is fair in that they would be happy to participate in the joint production process. They do so because of cost savings. If the production of multiple outputs in public spheres can be thought of as joint activities or collaborative activities, a method that brings some insights is the Shapley Value, a cooperative game theory concept developed by Lloyd Shapley in 1953. It has been applied to cost sharing in many situations (Kolker 2019; Lemaire 1984; Young, Okada, and Hashimoto 1982).

We introduce the concept of Shapley Value in the standard form and show how it can be applied. Joint production is worth doing in the first place if the combined subset of production processes (similar to the subsets in the Panzar-Willig definition above) is more costly. Thus, we generate surplus (cost savings) through joint production. There are n outputs and possible partitions as shown above: we can think of stand-alone production, grand production (in which all outputs are joint production) or production processes of different independent combinations of outputs. We can say each output is the responsibility of one organisation (or department) whatever the means of production are. The combination of outputs should be thought of as coalitions of collaborative activities of organisations. The Shapley Value calculates the value of each output by calculating the average costs of an output through different permutations of production processes involving that output. The explanation of Shapley Value follows the exposition by Roth and Verrecchia (1979).

Any combined production or 'coalition of players' (using the language from game theory) yields a value of $c(S)$, where S denotes a coalition and the function the total cost generated by the production process followed by S. There are $N = \{1, 2, \ldots, n\}$ types of outputs or number of agencies. We will consider all possible coalitions for agency/output $i \in N$. For each coalition, S denotes the number of outputs in the coalition. The cost of an output is determined by the weighted average of the marginal cost of an output of a possible joint production. The marginal cost of an output from a coalition is the following: $c(S) - c(S - \{i\})$. The marginal cost within the coalition of output i is the total cost in the coalition minus the cost in a coalition with all members of S but not i. The cost that can be attributed to output i is the following:

$$b_i = \sum_{S \subset N} \frac{(s-1)!(n-s)!}{n!} [c(S) - c(S - \{i\})].$$

Value b_i is the expected marginal cost added by each output; the weights allow for production arrangements to come in random order (all possible ordering) within combinations through which production can take place. There are $(s-1)!(n-s)!$orderings for outputs such that output i is produced after all others are produced. One way to calculate b_i is to state all orderings of the outputs and examine the cost contribution of the newer output in the ordering in the joint production that is being considered. The values from the ordering are then averaged. Table 1 details the value for each of these outputs using the example used earlier to determine EoS.

In Table 1, we see that overall joint production costs less than the stand-alone production process. The first column shows the six possible orderings. Taking the first line: output 1 is first produced by itself and if output 2 joins in, we add the cost of producing the second output in joint production with output 1—from above $C(P_{12})$, and, lastly, we add the marginal cost of producing the third output in the overall joint production $C(P_{123})$. The three values are successfully: $C(P_1) = 35, C(P_{12}) - 35$ or $50 - 35 = 15$ and $C(Y_S) - 50$ or $80 - 50 = 30$.
Note the production costs from Table 1 are cheaper than stand-alone costs. Further, none of the costs in the partitions from above yield a cheaper production process; for example, the costs of outputs 1 and 2 combined from Table 1 are $46 < C(P_{12})$. Thus, if these outputs were initially to be produced by different organisations, the organisations would theoretically agree instead to joint production, as there are cost savings. We may say that organisations would participate in the joint production because the joint production yields cheaper costs relative to any other production arrangements. One can imagine that each of the three departments is told to produce their outputs, and they know their stand-alone costs. They seek out joint production to save costs. Each sees

Table 1. Shapley value and costs from joint production[13].

Output ordering	Cost of output 1	Cost of output 2	Cost of output 3
y_1, y_2, y_3	35	15	30
y_1, y_3, y_2	35	15	30
y_2, y_1, y_3	30	20	30
y_2, y_3, y_1	25	20	35
y_3, y_1, y_2	25	15	40
y_3, y_2, y_1	25	15	40
Costs	29.17	16.67	34.17

individual costs lower and that joint production is cheaper than other combined production processes. The Shapley Value will not always yield a result where all participants will find it advantageous to join; they may have better options. Certain conditions regarding the cost structures need to be met. These conditions are harder to meet with a greater number of outputs (Lemaire 1984) but are not unreasonable. Notice that the Shapley Value yields a solution where no department subsidises any other department; there is no cross subsidy.

Earlier in section 3, we tested for economies of scope; in this section, we were able to calculate the cost of each individual output. The information needed for both exercises is the same. We note, however, that the information needed may not be easy to come by.

How should these costs be understood? The Shapley Value allows us to calculate the costs of individual outputs through cost savings. How can we distribute the gains made from synergy? In practical applications, as suggested by many authors, we are not able to calculate the exact costs involved in producing each of these outputs from a joint production process in terms of the exact intensity of use of resources. One may get different costs than the Shapley solution if somehow intensity of usage of inputs was determined for each output and assigned a cost. The total cost of the joint production is determined through the ingredient approach, but the division of this cost does not rely on measuring the intensity of usage of inputs for each output.

V. Limitations

This paper discussed when joint public production processes may enhance the efficiency of public projects in developing countries. It then showed how costs can be apportioned to different outputs. The Panzar and Willig's (1981) definition to check for efficiency of joint production relied on knowing the costs of alternative means of production. Further, the calculation of the Shapley Value relied on knowing the same set of information as did the application of the given definition of EoS. The connection between EoS and the Shapley Value is standard practice (see Mirman, Tauman, and Zang 1985). In the CEA literature applied to developing countries, it has been difficult to calculate ICER as defined above because for a given intervention we may not find in the status quo an intervention that produces the similar result as the new interventions for which CEA is being conducted. An alternative approach to ICER has been suggested for developing countries and for most CEA studies conducted by the World Health Organization (Murray et al. 2000; Tan-Torres Edejer et al. 2003). In developing countries, comparators may be few. The need for information detailed here may thus be unrealistic for developing countries. However, it is possible that better reporting of costing methods and contexts in which CEA were conducted can inform us of approximate costs of alternative combined ways we can produce outputs from development projects.

We have also suggested a solution to cost-sharing that may not be intuitive. It is possible that organisations would find measuring the intensity of usage or simply dividing the total costs by the number of participants more appealing. For the evaluation of MVP, costs from alternative means of producing the services that MVP provided were collected through systematic reviews. If it were possible to show that at least step 1 (S1 from above) to confirm EoS held true, perhaps joint production should occur. However, for truly imputing the correct cost of the goods, through applying Shapley Value, we would need more information. It is likely that if, after putting forth a budget that an organisation had allocated for an intervention, it received some reimbursement through joint production, it is likely to cooperate. Thus, cost sharing of inputs in the implementation of multiple interventions or over full joint production may depend on anticipated savings over some estimation of costs. The possibility of generating cost savings and finding ways to divide the savings may incentivise multi-sectoral collaboration. Given that the Shapley Value leads to a fair allocation of savings, equally dividing savings will theoretically be less favoured than the Shapley Value.

VI. Conclusion

We show that the public joint production process must be rooted in economies of scope and offer precise ways to examine where there may be economies of scope in joint production. If joint production is warranted, shared input costs should be estimated. Although integrated development projects have been implemented (Sachs et al. 2004), not much thought has been given as to what individual outputs may cost (Banerjee et al., 2015), or perhaps even the total cost of the project by accounting resource usage.

Masset, García-Hombrados, and Acharya (2020) show that an important IDP did not generate cost savings when the entire project was compared to the combined costs of possible stand-alone activities, a partial test for EoS. The tests for full EoS require a great deal of information on project alternatives, the same amount to calculate the Shapley Value. This type of information is not usually available, because authors do not report on the context in which CEAs are conducted. Jin et al. (2005) modelled the cost function using a sample of research centres and using explanatory variables. In principle, one could do the same with a sample of projects implemented together and independently. Along this line, Banerjee et al. (2022) test to see if the transfer of a productive asset or access to savings is enough to generate impacts comparable to a multifaceted programme that includes both the part mentioned and training and coaching. They do not, however, examine the implications for costs. Here, it would be important to report costs along with the outputs generated.

Publicly provided outputs are often the result of joint production or the sharing of inputs in the production processes. Although cost-effectiveness analysis literature has paid scant attention to this issue (Shepherd, Zeng, and Nguen 2015; Vassal et al. 2018), we find rules for dividing costs across projects (Drummond et al. 2007) and recognition of economies of scope. Authors conducting CEA, especially in health, note the use of building and capital goods. These factors make up the health system. In most studies, however, these costs are not made explicit as most CEAs do not include much information about the context in which the study took place. For developing countries, these backgrounds are diverse and may affect both costs and impact.

We show that it is possible to divide up savings made from joint production. We offer a few methods to examine how the associated costs can be calculated though our list of methods is not exhaustive (Lemaire 1984). CEA researchers should examine the literature on cost sharing; Young, Okada, and Hashimoto (1982) give guidance to some of this literature. Given that it is hard to observe the intensity of resource usage in joint production processes, the methods proposed here, based on dividing the savings, offer a clear assignment of costs if we are able to ascertain what the alternative methods to input sharing might cost. However, a greater understanding of this literature is warranted. There is a need for further research on how methods such as Shapley Value or the Moriarty methods can be more easily used while conducting CEA. The Shapley Value is well suited to analyse integrated development projects.

We urge that those carrying out CEA to consider joint project activities and recognise that costs and productivity are affected by resource sharing. Holistic reporting on costs that consider the contexts and the joint production processes within which most projects take place is important in developing country contexts. This information would be helpful in scaling up. Many donors believe that integrated health projects have been more efficient in developing projects. Yet, a 2018 fiscal year report for a USAID project in Congo showed no plans or strategy to discover project efficiency (USAID 2018). Till this date, there has not been much attempt to document such efficiency so that they can be helpful in project implementation.

Notes

1. The generic term cost-effectiveness analysis (CEA) is used for what are sometimes called in the literature cost-utility analysis, cost-efficacy analysis, and cost-effectiveness analysis. Cost-utility analysis is sometime distinguished from cost-effectiveness analysis when outcomes are assigned a subjective valuation, such as quality-adjusted or disability-adjusted life years (see Drummond et al. 2015). The costing approaches presented here are applicable to all these types of analysis. It is also relevant to cost-benefit analysis. Sometimes the generic term of economic evaluation is used; but this may be misleading as analysis may sometime ignore cost to the economy and focus on costs to a particular organisation.
2. Analysis presented here can be extended to all forms of what some call economic evaluation. As we talk of production and costs together, we envision an input–output relation.
3. Scholarship and sex education (two outputs) facilitate education attainment and sexual health knowledge among participants. Participants may be more likely to postpone first pregnancy (development outcome), yielding welfare gains (utility).
4. Public production may occur across departments, necessitating a greater need for assessing costs of singular outputs.
5. Although we focus on technical efficiency, the costing methods are appropriate for CEA, CBA, and cost-utility analysis.
6. We will use the term joint production to mean any production process where outputs of the production processes are multiple. We make a distinction as to production externality and when we refer to a process that is a joint production or producing multiple outputs. Governments may want to coordinate simultaneous activities of departments if positive externalities arise and then reward some savings to the implementing departments. They may also want sectors to cooperate work together on projects through active engagement. Although some of the arguments here are applicable to both situations, we want to focus on the actual joint production aspects. Although there might be positive production externalities to produce a type of agglomeration effect, for the purpose of this paper this is ignored.
7. The CER when outcomes are concerned there would be a status quo outcome. For cost-efficiency analysis, if the new project is not replacing any old project, then there is not status quo output.
8. Time motion studies can be used to analyse the production of a single output or for a joint production process. They are especially useful when production processes are discrete and each process might be slightly different, for example, surgery.
9. Following upon the MDGs, international development community endorsed sustainable development goals as the universal call to end global poverty. The United Nations Development programme website states the following: The 17 SDGs are integrated – they recognise that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability (United Nations Development Programme 2022).
10. Reddy and Heuty (2008) showed a plausible example with two products, malaria and tuberculosis, having a joint cost function that is convex; the interaction could be from joint use of inputs or externality such as spillovers in activities to control one of the illnesses – positive externality. There is also the possibility of negative externality, due to, say, overwhelming cases of malaria reducing resources needed to treat or prevent tuberculosis.
11. Our analysis can extend to the case where there is positive externality; but again we avoid the discussion to focus more on the process of cost sharing.
12. Capital goods when used in CEAs are priced at amortised value across its usage time; the time unit can be a year.
13. The same answer is obtained through direct application of the formula. Note for any of the 3 outputs there are 4 possible ways to produce the output. Taking output 1: we obtain stand-alone production, production with either 2 or 3-two combinations and lastly production with both 2 and 3 in different ordering. To illustrate, for the stand-alone production, there is only one coalition member; thus, the weight is $((1-0)! \times (3-1)!)/3!$, or 1/3. Cost of output 1 is the following: $b_1 = (1/3 \times 35) + (1/6 \times 30) + (1/6 \times 25) + (1/6 \times 25) + (1/6 \times 25) = 29.17$.

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